

SECTION 23 34 14

FAN-MOTOR UNITS FOR TUNNEL VENTILATION

PART 1 – GENERAL

1.01 SECTION INCLUDES

- A. The work of this Contract Specifications Section includes furnishing, installing, and testing axial-flow fan-motor units and appurtenances as shown on the Contract Drawings.

1.02 RELATED SECTIONS

- A. Section 23 05 93, Testing, Adjusting, and Balancing for HVAC
- B. Section 23 09 01, Fan Control Panel
- C. Section 23 31 14, Ductwork for Tunnel Ventilation
- D. Section 23 33 14, Dampers for Tunnel Ventilation
- E. Section 23 33 20, Sound Attenuators for Tunnel Ventilation
- F. Section 26 05 13, Medium Voltage Cable
- G. Section 26 05 24, Low Voltage Wires and Cables
- H. Section 26 24 25, Medium Voltage (4.16 kV) Motor Controllers

1.03 MEASUREMENT AND PAYMENT

- A. General: Separate measurement or payment will not be made for the work required under this Section. All costs in connection with the Work specified herein will be considered to be included or incidental to the Work of this Contract.

1.04 REFERENCES

- A. Where materials or equipment are required to conform to referenced industry standards, the current edition of the most recent revisions as of the date of Notice to Proceed shall apply.
- B. Contractor may propose for approval alternate standards to those listed herein, provided that the standards are submitted in the English language, with a point-by-point comparison between the specified and alternate standards included in the submittal. The requirements of proposed alternate standards shall be at least as stringent as the specified standards.
- C. Reference Standards

- 1. Air Moving and Control Association (AMCA):

- a. 204, Balance Quality and Vibration Levels for Fans.
 - b. 210, Laboratory Methods of Testing Fans for Aerodynamic Performance Rating.
2. American Bearings Manufacturers Association (AFBMA).
 - a. 9, Load Ratings and Fatigue Life for Ball Bearings.
 - b. 11, Load Ratings and Fatigue Life for Roller Bearings.
3. American National Standards Institute (ANSI):
 - a. C1, General Requirements of a Quality Program.
 - b. S12.36, Survey Methods for Determination of Sound Power Levels of Noise Sources.
4. American Society of Mechanical Engineers (ASME):
 - a. B18.21.1, Lock Washers.
5. American Society for Non-Destructive Testing (ASNT)
6. ASTM International (ASTM):
 - a. A 36, Carbon Structural Steel.
 - b. A 193, Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service.
 - c. A 194, Carbon and Alloy Steel Nuts for Bolts for High-Pressure and High-Temperature Service.
 - d. A 388, Recommended Practice for Ultrasonic Examination of Heavy Steel Forgings.
 - e. B 117, Standard Practice for Operating Salt Spray (Fog) Apparatus.
 - f. B 247, Aluminum Alloy Die Forgings, Hand Forgings and Rolled Ring Forging.
7. American Welding Society (AWS):
 - a. D1.1, Structural Welding Code - Steel.
 - b. D1.3, Structural Welding Code - Sheet Steel.
8. Institute of Electrical and Electronic Engineers (IEEE):
 - a. 112, Test Procedure for Polyphase Induction Motors and Generators.
9. International Organization for Standardization (ISO)
 - a. 1940, Mechanical Vibration - Balance Quality Requirements for Rotors in a Constant (Rigid) State - Part 1: Specification and Verification of Balance Tolerances.

10. National Electrical Manufacturer's Association (NEMA):

- a. MG-1, Motors and Generators.

11. National Fire Protection Association (NFPA):

- a. 70, National Electrical Code (NEC).
- b. 130, Standard for Fixed Guideway Transit and Passenger Rail Systems.

12. Steel Structures Painting Council (SSPC):

- a. PA-1, No. 1 Shop, Field and Maintenance Painting.
- b. PA-2, Method for Measurement of Dry Paint Thickness with Magnetic Gauges.
- c. SP-3, Power Tool Cleaning.
- d. SP-10, Near White Blast Cleaning.

1.05 COORDINATION

- A. The fan-motor unit manufacturer shall coordinate with the sound attenuator manufacturer to confirm that combined fan-attenuator noise (fan sound power level minus attenuator dynamic insertion loss) does not exceed the combined fan-attenuator noise shown in the Equipment Schedule in the Contract Drawings. The Contractor shall ensure that the fan-motor manufacturer and the sound attenuator manufacturer jointly provide written certification that the fan-motor units and attenuators have been coordinated so that combined fan-attenuator noise does not exceed the combined fan/attenuator noise shown the Equipment Schedule in the Contract Drawings.
- B. Contractor shall ensure that the fan-motor manufacturer and the power and controls system provider for the emergency ventilation system have been coordinated. The Contractor shall ensure that the Fan, Power and Controls suppliers jointly provide written certification that the respective equipment has been coordinated so that the factory and field test performance of the fans can be repeated with the field installed power, controls and motor starting equipment.
- C. Contractor shall ensure that the fan-motor unit manufacturer confirms with the sensor and probe manufacturer(s) the suitability of the sensor / probe mounting to the motor housing and that any shaft milling or other modifications for the mounting and operation of the sensors / probes are compatible. Contractor shall ensure that the motor manufacturer provides probe / sensor enclosure design and mounting means.

1.06 SUBMITTALS

- A. Provide submittals in accordance with Contract Specifications Section 01 33 00, Submittal Procedures, Contract Specifications Section 01 33 23, Shop Drawings, Product Data, and Samples, Contract Specifications Section 01 42 19, Reference

Standards, and the requirements of Article 1.06 herein. In case of any conflict, the more stringent requirements will take precedence. Drawings and Graphs shall be readable and shall be submitted on a minimum of 11" x 17" size paper.

- B. Prior to award of contract to fan-motor manufacturer, Contractor shall submit a complete list of projects on which similar fans for rail or transit station projects in the United States have been applied. List shall include:
1. Name of owner or user (include the Owner's installations, if any).
 2. Contract number(s).
 3. Original installation date(s).
 4. Current condition of equipment.
 5. A list of all known failures for the past 10 years, including their apparent causes, corrective work effected (including design changes), and a description of equipment service and operating conditions.
- C. Within 90 Days after Notice to Proceed, Contractor shall submit evidence of his qualifications, including, but not limited to the following data:
1. Theoretical fan-motor composite performance curves for equipment proposed to be furnished under this Contract.
 - a. Fan-motor unit performance curves from shut-off to free delivery shall have the following data plotted as ordinates versus airflow rate, in cubic feet per minute, as abscissa:
 - 1) Fan total pressure, inches of water.
 - 2) Fan static pressure, inches of water.
 - 3) Fan velocity pressure, inches of water.
 - 4) Total efficiency, percent.
 - 5) Horsepower input to fan impeller.
 - 6) Kilowatt input to the motor.
 - b. Separate curves shall be furnished for forward and reverse direction. Each curve shall be identified.
 - c. System resistance curves shall be plotted for each rotational direction with the point of operation indicated.
 - d. Theoretical performance curves for each rotational direction shall be plotted for fan-motor units for the installed motor horsepower for the following blade pitch angles:
 - 1) Maximum blade pitch angle for installed motor horsepower.
 - 2) Minimum blade pitch angle.
 - 3) Design blade pitch angle.

- 4) A minimum of four intermediate pitch angles between maximum and minimum blade pitch angle other than design pitch angle.
- e. Acceleration time for each rotational direction from standstill to operating revolutions per minute (rpm). Plot operating rpm as abscissa and acceleration time as ordinate.
- f. The fan load torque and motor torque curves from standstill to operating speed. Plot percent revolutions per minute as abscissa and percent full-load torque as ordinate.
- g. All performance curves shall be plotted on minimum 11" x 17" sheets to such scales and with a grid that will make it possible to read the data accurately.
- h. The following information shall be indicated on each theoretical and actual performance curve:
 - 1) Contract title.
 - 2) Contractor's name.
 - 3) Name and address of fan manufacturer.
 - 4) Fan designation number.
 - 5) Fan housing inside diameter in inches.
 - 6) Fan outlet area in square feet.
 - 7) Fan rotor hub diameter in inches.
 - 8) Fan speed in revolutions per minute.
 - 9) Number of fan blades.
 - 10) Design blade pitch angle.
 - 11) Rotational moment of inertia of fan rotor assembly in pounds-foot squared.
 - 12) Maximum acceleration time required to start fan-motor unit from rest and accelerate it to operating speed against the design duty resistance, in seconds, at rated voltage.
 - 13) Air density in pounds per cubic foot.
 - 14) Direction of airflow (forward or reverse).
 - 15) The following data at the operating point:
 - a) Fan static pressure in inches of water.
 - b) Fan total pressure in inches of water.
 - c) Fan outlet velocity pressure in inches of water.
 - d) Fan outlet velocity in feet per minute.
 - e) Fan total efficiency in percent.
 - f) Motor efficiency in percent at operating point.
 - g) Fan-motor unit total efficiency in percent.
 - h) Horsepower input to fan impeller.
 - i) Kilowatt input to motor.

2. Theoretical fan motor performance curves covering the entire range of load conditions from no load to not less than 115 percent of full load at 110 percent, 100 percent, 90 percent, and 85 percent of motor rated voltages.
 - a. Composite curve for each motor horsepower size plotted with abscissa as horsepower output and ordinates as:
 - 1) Current in amperes.
 - 2) Speed in rpm.
 - 3) Efficiency in percent.
 - 4) Power factor in percent.
 - 5) Torque in foot-pounds.
 - b. Composite curve for each motor horsepower size plotted with abscissa as speed in revolutions per minute and ordinates as:
 - 1) Motor current in amperes.
 - 2) Motor torque in foot-pounds.
 - 3) Fan torque in foot-pounds.
 - 4) Motor acceleration from standstill to operating speed in seconds.
 - c. Motor Winding and Bearing Temperature Test: Time in minutes as abscissa versus temperature rise in degrees Celsius as ordinates when operated at full voltage and speed.
 - d. Insulation Resistance-Temperature Test: Test result values shall be plotted on semi-logarithmic graphs, the insulation resistance values as logarithmic ordinates and the temperature values degrees Celsius or degrees Fahrenheit as uniform abscissa.
 - e. In addition, for comparison purposes, a curve indicating the safe operating value of insulation resistance shall be plotted on the same sheet with the insulation resistance temperature test curve.
 - f. The following information shall be stated on each motor theoretical and actual performance curve and data sheet:
 - 1) Contract title.
 - 2) Contractor's name and address.
 - 3) Name and address of motor manufacturer.
 - 4) Fan designation number in which the motor forms a part.
 - 5) Motor type.
 - 6) Motor serial number.
 - 7) NEMA Motor frame size.
 - 8) Motor nameplate horsepower rating.
 - 9) Electrical characteristics (voltage-phase-frequency).

- 10) Full-load and no-load current in amperes.
 - 11) Locked-rotor current in amperes.
 - 12) Motor torque in lb-ft including locked rotor torque, pull-up and breakdown torque.
 - 13) Full-load slip.
 - 14) Direction of rotation of motor.
 - 15) Speed in revolutions per minute.
 - 16) Service factor.
 - 17) Rotational moment of inertia of fan rotor (minus motor) in pounds-foot squared.
 - 18) Rotational moment of inertia of motor in pounds-foot squared.
 - 19) Power Factor at 100 percent, 75 percent, and 50 percent load.
 - 20) Motor torque and fan load torque curves indicating net torque margin.
 - 21) Motor efficiency at 100 percent, 75 percent, and 50 percent load.
 - 22) Electrical characteristics of space heater, including voltage and kilowatt input.
 - 23) Motor thermal curve.
 - 24) Verify proper operation of the proximity probes indicating the sense and speed of rotation of the fans by comparing results to items 14 and 15 above.
3. Fan-motor unit theoretical sound power levels in decibels (re: db 10-12 watts) shall be submitted for both directions of airflow for reversible fans at full speed.
 4. Name of independent testing company proposed to be used to conduct independent motor factory test.
 5. Manufacturer's quality assurance program in accordance with ANSI C1.
 6. List of components proposed to be purchased from other manufacturers, giving name of manufacturer, type and characteristic of each item and applicable data requested under Article 1.06B.1 through Article 1.06B.5 herein above.

D. The Contractor shall submit the following:

1. Certified Shop Drawings including Bill of Materials for fans, motors, fan motor unit bases, installation drawings, installation instructions, dimensioned drawings for anchor bolt locations, and any additional data required to demonstrate compliance with Contract Documents. Shop Drawings shall indicate operating and shipping weights of each component and fully assembled unit.
2. Comprehensive General Arrangement Drawings of fan-motor unit assembly including transition and straight ductwork, flexible connections, sound attenuators, dampers, etc.

3. Drawing of fan blades and hub identifying index marks for setting blade angles.
 4. Dimensioned drawings including mounting details of fan and Instrument Panel.
 5. Shop Drawings indicating the size and location of each foundation for the fan-motor units in the ventilation structure, reinforcing bar requirements for these foundations and the expected static and dynamic forces and moments generated by the equipment.
 6. Submit basis and justification for material selection for fan blades and hub. Submit data on mechanical properties of the fan blades and hub and data on fan blade and hub yield strength at 482 degrees Fahrenheit. Submit calculations to confirm that the blade and hub stress does not exceed 60 percent of the component material yield strength at 482 degrees Fahrenheit with fan operating at maximum speed.
 7. Submit calculations taking into account the differential rates of expansion of dissimilar materials, showing the clearance of the blade tips to the fan housing. The Contractor shall ensure that the fan manufacturer submits a table showing the maximum and minimum blade tip clearance at 0, 35, 60, 100, and 482 degrees Fahrenheit.
 8. Data sheet on motor bearing lubricant, Manufacturer's Safety Data Sheet (MSDS), frequency of lubrication and amount of lubricant to be supplied during lubrication.
 9. Complete factory and field test procedures.
 10. List of technical support items specified and list of any additional support items required.
 11. Motor terminal and auxiliary box drawings including electrical wiring diagrams of motor and monitoring device connections.
 12. Complete fan and motor nameplate drawings.
- E. Within 21 Days after successful completion of tests specified herein and of any additional tests conducted at Contractor's own option, Contractor shall submit the following:
1. Certified test results for all fan and motor factory tests conducted. All test data shall be bound in one report. The test report shall be indexed and cross-referenced in an easily understood manner.
 2. All records and results of non-destructive examinations made at completion of each examination.
 3. Field test results.
 4. Radiographic inspection films.

5. Furnish Shop Drawing of each fan impeller indicating the fan blade number and weight of each fan blade and blade and hub x-ray numbers with the factory test report.

F. Operation and Maintenance Manuals

1. At least 30 Days before shipment of the first fan-motor unit, Contractor shall submit for approval three copies of the Operation and Maintenance (O&M) Manual, which shall provide technical support for fan-motor unit maintenance. After approval of the preliminary submittal and having made all necessary corrections and amendments required, Contractor shall provide six (6) additional copies of the approved dated O&M Manual. One master camera-ready set shall be included as one of the 6 copies to permit additional copies to be made. The master camera-ready set shall be clearly marked as such on the outside. An electronic copy of the O&M Manual text, drawing and catalog cut files shall also be provided. The O&M Manual shall provide a clear explanation of the theory, operation, and maintenance of the equipment accompanied by photos and schematic, wiring, and mechanical assembly diagrams, as required. The O&M Manual shall be indexed and cross-referenced in an easily understood manner. The O&M Manual shall be loose-leaf bound and shall include, but not necessarily be limited to, the following information:
 - a. Troubleshooting and fault isolation procedures for on-site level repair.
 - b. Fan and motor removal and replacement procedures, including instructions on aligning motor and fan impeller in fan housing.
 - c. Fan and motor disassembly and re-assembly instructions.
 - d. Procedure for static and dynamic rebalancing of fan impeller in the field.
 - e. A list of the components, which are replaceable at the three possible levels of maintenance: on-site, shops, and the Fan Manufacturer's facility.
 - f. A test procedure to verify the adequacy of repair work for fan and motor.
 - g. A preventive maintenance schedule and instructions detailing lubrication of moving parts and monitoring of sound and vibration levels.
 - h. Procedures for separately removing and replacing motor, fan rotor, and blades as well as procedures for removing a complete fan-motor unit without disassembly.
 - i. A list of special tools provided by the fan manufacturer.
 - j. Metal templates for blade angle setting for each fan.
 - k. A list of tools and test equipment required to perform all maintenance tasks.
 - l. Approved Shop Drawings.
 - m. Fan and motor factory test reports.
 - n. Field testing procedures and list of required equipment.

- o. Methodology for determining whether a fan can continue to be operated after exposure to a fire event.
 - p. The latest service bulletins with dates which describe service procedures.
 - q. Contractor shall notify the District Representative of any revision to service bulletins that are included in the O&M Manual described herein for a period of five years from the date of facility opening for revenue service.
- G. Technical Support Items: At least 30 Days before shipment, Contractor shall submit the following:
 - 1. Ten sets of special tools shall be provided in total. Special tools shall be those tools, which are required to specifically service or repair the fan unit which is being supplied and that are not normally carried in a general mechanic's toolbox. Special tools would include torque wrenches, large wrenches or sockets (for bolts 3/4-inch or larger), templates for blade adjustment, calibration equipment for sensors / probes, etc.
 - 2. Tabulation of technical support items necessary to maintain the fans procured under this Contract. This table will become a working document to be used by the District in the procurement of support items, and shall be updated as changes occur. The technical support items shall be grouped by equipment and components. This list for each item shall give complete ordering and procurement information for that item, including quantity required to maintain inventory for 500 hours operation. Each item listed shall contain at least the following information:
 - a. Item name.
 - b. Description rating.
 - c. Estimated operating life.
 - d. Current price.
 - e. Manufacturer's name.
 - f. Part name.
 - g. Drawing reference number.
 - 3. Items that are common to more than one fan shall be cross-referenced. A column, immediately after the columns indicating recommended spare quantities, shall indicate expected delivery time in excess of 60 Days.
 - 4. The Contractor shall submit a recommended spare parts list in accordance with Contract Specifications Section 01 78 44, Spare Parts and Maintenance Manuals.
- H. Prior to Substantial Completion the Contractor shall submit training materials in accordance with Contract Specifications Section 01 79 00, Demonstration and Training.

- I. Record Drawings: Submit Record Drawings in accordance with Contract Specifications Section 01 78 39, Contract Record Documents.
- J. Prior to Substantial Completion the Contractor shall submit information on the warranty (see Supplementary Conditions Article SC4.7, Guaranty of Work).
- K. Templates for Setting of Blade Angles: Contractor shall provide metal templates or other approved devices to facilitate settings of blade angles in the field. One template shall be provided attached to each fan unit in a location that is subject to the District Representative approval. One template shall be provided with each O&M Manual.

1.07 QUALITY CONTROL

- A. Source Quality Control
 - 1. Fans shall be the product of a single manufacturer whose name shall appear on the theoretical fan-motor unit performance curves and other data submitted.
 - 2. All fan motors shall be the product of a single manufacturer whose name shall appear on the theoretical motor performance curves and other data submitted.
- B. Manufacturer's Qualifications: Contractor shall ensure that the fan manufacturer submits documents to show continuous and current experience in the design, assembly, and testing of axial-flow tunnel and Station ventilation fans and experience in the design and fabrication of units capable of operating in an airstream at a temperature of not less than 482 degrees Fahrenheit for not less than one hour and an airstream of not less than 392 degrees Fahrenheit for not less than two hours.
- C. Welding: All components in this Contract requiring welding shall be welded as follows:
 - 1. Code Requirement: Welding shall conform to the requirements of AWS D1.1 and AWS D1.3.
 - 2. Welder Qualification: Welders welding on the work of this Contract shall be certified in accordance with AWS D1.1. Copies of welder certifications shall be provided.
 - 3. Process: The welding process employed on the Work of this Contract shall be the shielded metal arc process, in accordance with AWS D1.1.

1.08 STORAGE AND PROTECTION

- A. Storage: Store all materials and equipment in dry, ventilated, weather tight enclosures.

- B. Protecting Machined Surfaces: Apply a rust preventive on machined surfaces such as flanges and shafts. Use material of a type that is easily removable with solvent during equipment installation.
- C. Protecting Openings: Close pipe connections, ends, and other openings with easily removable plugs, stoppers, or flange covers.
- D. Motor space heaters shall be energized within 24 hours after the unit is delivered to the storage facility or Contract Construction Jobsite. The motor heaters shall also be energized while in storage awaiting the fabrication of the fans, in accordance with the manufacturer's instructions.

1.09 CONTRACT/JOBSITE CONDITIONS

- A. Design Temperature Conditions. Fan-motor units and all parts thereof shall be capable of withstanding the effect of all stresses and loads under starting, operating, and reversing conditions specified. Fans and all components shall be capable of operating for not less than 1 hour in an ambient temperature of not less than 482 degrees Fahrenheit and for not less than an additional two hours at not less than 392 degrees Fahrenheit.
- B. Fans, motors, and components shall be capable of withstanding sudden temperature changes because of fire between the extremes of 35 and 482 degrees Fahrenheit or vice versa in a time frame of 20 seconds.
- C. Fan-motor units shall be designed for the orientation, horizontal or vertical, shown on the Contract Drawings, and they shall be designed and built to serve an underground environment and to function under conditions of high humidity and high temperature and the inlet and outlet conditions as indicated.
- D. Power Supply. Power will be supplied at the rated characteristics as shown on the plans.

1.10 SPARE PARTS

- A. Provide the District Representative with one spare impeller hub and one complete set of spare fan blades for each size hub and blade provided. Store spare hub and blades in secure storage containers with permanent labels identifying number, type, manufacturer and the District's Construction Contract Number.
- B. Provide the District Representative with one spare set of sensors and probes identical to the sensors and probes supplied for each motor horsepower size fan-motor unit. Store spare sensors and probes in secure storage containers with permanent labels identifying number, type, manufacturer and the District's Construction Contract Number.
- C. Provide the District Representative with one spare fan motor identical to the motors supplied for each motor horsepower size fan-motor unit. Store spare motor in secure storage containers with permanent labels identifying number, type, manufacturer and the District's Construction Contract Number.

PART 2 – PRODUCTS

2.01 FAN-MOTOR UNITS

A. Description

1. Fan-motor units shall conform to all the regulatory requirements of the California Building Code, NFPA 70 and NFPA 130 where applicable.
2. Fans shall be axial-flow type with reversible operation. Fan-motor units shall be required to operate in the forward or reverse direction of airflow, with a capability of starting, stopping, or reversing the direction of flow at any time.
3. Fan-motor units shall be direct-driven by internally-mounted electric motors, with provision for manual adjustment of the individual blade angle. Fan-motor units and their supports shall be designed and constructed for the arrangement shown on the Contract Drawings.
4. Motors shall conform to the requirements of Article 2.03 contained herein. Motors shall not be provided with self-contained thermal protective devices.

B. Fan-Motor Unit Design Requirements

1. Fan-motor unit performance shall be rated for the airflow and total pressure specified on the Drawings at the air density shown on the Contract Drawings.
2. Fan-motor unit performance curves for either direction shall rise continuously with decreasing flow between free delivery and 60 percent of free air delivery or to maximum horsepower rating. Fans shall be capable of operating continuously at specified design points for forward and reverse flow. For the purpose of this Contract, forward flow shall be designated as exhaust mode (airflow from trainway to atmosphere) and reverse flow shall be designated as supply mode (airflow from atmosphere to trainway).
3. Fan-motor units shall have a total efficiency of not less than 60 percent. Including motor efficiency defined in Article 2.03 herein.
4. Fan-motor units shall be capable of accelerating from a standstill to rated rotational speed at the design duty air quantity and pressure, in either direction, in not more than 15 seconds and without failure of any part of the unit, when started across-the-line with rated voltage at the motor terminals and a voltage dip of not more than 15 percent of the rated voltage. Fan-motor units shall be capable of reversing to full speed from either direction of airflow and rotation during an emergency within 15 seconds when started across-the-line with rated voltage at the motor terminals and a voltage dip of not more than 15 percent of the rated voltage, after a 10-second delay between power interruption and the energizing of the motor for the reversed rotation, without failure of any part of the unit.
5. Brake horsepower input to fan impeller shall not exceed the nameplate horsepower rating of the fan motor when operating in either direction of airflow.

6. Pressure variations of plus or minus 1.50 inches water gauge induced by external causes shall not result in movement of the fan operating point along the total pressure fan operating curve into the region of unstable operation. The definition of the region of unstable operation shall be any point that is not on the negatively sloping portion of the pressure curve. This requirement does not affect the horsepower requirement for the design operating point.
7. Any indication of a flat or unstable region in the fan curve shall be thoroughly evaluated to confirm the location of the unstable region in relationship to the operating point.
8. Fans shall not operate in stalling range of fan performance curve (region of unstable operation) during parallel operation (forward or reverse direction).
9. Fans shall have a stable operating characteristic in both directions of free flow over the range from 50 percent nominal flow to free delivery.
10. No fan blade or fan wheel impeller assembly shall have a natural frequency within plus or minus 10 percent of two, three and four times the operating frequency nor at the blade pass frequency defined as number of blades times natural operating frequency.

2.02 FAN FABRICATION

A. Impeller Hub and Blades

1. Impeller hub shall be fabricated of aluminum alloy castings, aluminum alloy forgings, steel or stainless steel, suitable for the specified performance, environment and temperature specified. Aluminum forgings shall be in conformance with the requirements of ASTM B 247.
2. Blades shall be forged aluminum. Blades shall be matched in pairs and be matched in fan sets. The matched pairs shall weigh within 0.2 percent of each other. Blades in the fan set shall be selected to weigh within one percent of all other blades in the fan set. Blades shall be manufactured of a homogeneous material and shall have no cast-in or embedded materials of any kind. Individual blades shall be secured to the hub by not less than four bolts per blade, or shall be clamped securely between the two halves of a split hub or between suitably designed and manufactured clamp plates.
3. Fan rotating components shall be designed such that no measured or calculated stress level shall exceed 60 percent of the components materials yield strength at design temperature of 482 degrees Fahrenheit.
4. The fan motor and hub assembly shall be balanced in the shop to not exceed a vibration velocity of 0.0196 IPS - Peak. Fan units shall comply with a maximum peak vibration velocity of 0.0392 IPS when installed in the actual system configuration on the fan support pad or foundation.
5. Blade bolts, hub bolts or clamp plate bolts shall be readily accessible. The pitch of the blades shall be manually adjustable without removing impeller from fan

unit. Pitch is defined as the angle formed by the chord line of a blade root cross-section and a line parallel to the direction of rotation. The ratio of the hub diameter to the fan housing diameter shall not be less than 0.35. The hub shall have index marks embossed or engraved to show the design operating blade setting and the blade settings for a minimum of five additional blade angle increments with not less than two on each side of the design setting. Engraving shall be done at a low stress location on the hub.

6. Blade tracking shall not exceed plus or minus 1/8 inch.

B. Fan Housings

1. Fan housings, including motor mounts and motor supports shall be fabricated of hot-rolled steel not less than 1/4-inch thick. Clearance between housing inner diameter and blade tips shall be sufficient to allow for thermal growth difference between fan blades and fan housing at a temperature of 482 degrees Fahrenheit. Fan housing shall be provided with split joints except for impeller section. Housing sections shall be bolted, and gasketed to facilitate disassembly and removal of motor, rotor, shaft and bearings without removal of entire fan-motor unit or any part of adjacent ductwork.
2. Welds located in the airstream shall be ground smooth. Flanged rings shall be continuously welded to the outer periphery at each end of the housings, or flanges may be rolled as part of the housing. Flanges shall be not less than three inches wide and not less than fan housing thickness. Flanges shall have punched or drilled holes equally spaced not more than eight inches on centers to permit adjacent duct elements to be bolted to the housings.
3. Provide remote lubrication fittings for lubrication of motor bearings from easily accessible location, as approved by the District Representative. All maintenance fittings, connections, access hatches, etc. shall be located on the same side of the fan housing.

- C. The rotor assembly shall be fastened to the motor shaft by means of an approved keyed positive locking device that is fully effective for both directions of rotation, for all blade angle settings, and for all conditions of operation specified. The rotor assembly shaft shall be an extension of the drive motor shaft and shall be restrained longitudinally by a locking fastener and shoulder connection. This connection shall not be a custom design.

- D. Motor mounts and motor supports shall be designed to support the entire weight of the impeller and the motor, and to maintain the alignment of the fan-motor unit assembly in the specified mounting orientation and to maintain vibration levels within the specified limits. Motor supports shall be sufficient in number to provide the required strength and rigidity and shall be continuously welded to the motor mount and to the fan housing. Fan motor and fan rotor assembly shall be totally enclosed within the fan housing and not protrude at either end of the fan housing.

- E. Nosepiece cover plates, access doors, and aerodynamic separation plates, where provided, shall be secured by means of positive fastening devices which are fully

effective for both directions of impeller rotation, for all blade settings, and for all conditions of operation specified herein.

- F. Fan-motor unit assembly supports shall be of carbon steel not less than 3/8-inch thick conforming to the requirements of ASTM A 36. Supports shall include fan-motor unit structural steel base with vertical supports for horizontal fan orientation (horizontal supports for vertical fan orientation) extending from the base to the fan housing centerline flange and with horizontal thrust plates for horizontal fan orientation (vertical thrust plates for vertical fan orientation) extending over the full length of the fan housing. Vertical supports and thrust plates shall be welded continuously to the surfaces with which they come into contact.
- G. Terminal Boxes. The motor leads for power, motor heater, monitoring and control shall be suitable for operation at Design Temperature Conditions Article 1.09A herein, wired to separate power and auxiliary terminal boxes conforming to NEMA 12 requirements mounted externally to the fan housing. The Power Junction Box and Auxiliary Box shall be rigidly secured to the fan housing or separate channel frame in a manner which will prevent vibration and air leakage and shall be capable of withstanding Design Temperature Conditions without causing fan failure. Terminal boxes shall be mounted on the fan casing in the location shown on the Contract Drawings and oriented to accommodate the conduit entry shown. Motor terminals and connectors shall be as described in Division 26. Control cables shall conform to the requirements of NFPA 130 and as described in Contract Specifications Section 26 05 24, Low Voltage Wires and Cables. Sufficient cable slack shall be provided to permit testing of cables without disconnecting any connections. Vibration detector cables shall have sufficient length to reach monitors installed in the Fan Instrument Panel. Provide amplifiers for monitoring sensors as recommended by the manufacturer.
1. Power Junction Box. Motor terminal box for power leads shall be at least one size larger than required by NEMA MG-1.
 2. Auxiliary Box shall have screw-type pressure terminal strips for terminating control wires, exterior mounting lugs, full cover gasket, hinged door, minimum inside dimension of 24 inches high by 24 inches wide by 12 inches in depth. Auxiliary boxes shall be sized to provide device and wiring clearances conforming to NFPA 70.
 3. In order to meet the requirements of NFPA 130 that covers the tunnel area, all cables running from the motors junction box and through ducts/plenum up to the Junction Box placed outside the tunnel section shall conform to the requirements of NFPA 130 and as described in Contract Specifications Section 26 05 24, Low Voltage Wires and Cables.
- H. Fan Instrument Panel shall be mounted remotely from the fan housing and shall have screw-type pressure terminal strips for terminating control wires, exterior mounting lugs, full-cover gasket, and hinged door, sized as required, for vibration monitor, RTD relays and associated wiring. Panel shall be sized to provide device and wiring clearances conforming to NFPA 70. Panel shall be NEMA 4X S.S. Enclosure 16 inches x 16 inches x 6 inches.

- I. Grease supply and relief lines shall be brought from each motor bearing to accessible lubrication fittings, external to the fan housing, accessible from the floor level of the fan room as approved by the District Representative. The lines shall not be less than 1/4 inch (nominal) in diameter and shall be fabricated of stainless steel or other corrosion resistant alloy, seamless metallic tubing. The tubing shall not be crushed or scored during installation and the lines shall have neither kinks nor sharp bends. Lines penetrating the housing shall be rigidly secured to the housings to prevent vibration of the lines and be provided with grommets. Grease supply lines shall terminate in straight lubrication fittings. Grease fittings shall only allow the proper amount of grease to each bearing. The bearing lubricant shall be capable of providing the lubrication properties specified by the bearing manufacturer under Design Temperature Conditions Article 1.09A herein and also at a temperature of 35 degrees Fahrenheit.
- J. All electrical connections, instrumentation connections, grease fittings, access hatches and etc. shall be located on the same side of the fan. Maintenance personnel shall not have to access both sides of the fan to perform maintenance and standard repair operations.
- K. Contractor shall provide a 1/4-inch thick silicone gasket between all adjacent companion flanges; width of gasket shall be same as flange width. Gaskets shall be capable of withstanding Design Temperature Conditions Article 1.09A herein without degradation of sealing ability and without emitting toxic or noxious fumes.
- L. Sufficient lifting eyes shall be provided on each fan assembly to facilitate on-site installation and removal of the fans.

2.03 MOTOR COMPONENTS AND CONSTRUCTION

- A. General Requirements
 - 1. Motors shall be of the totally enclosed, air-over, cast iron or steel round frame, induction type, continuous duty, variable torque, and shall be flange, pad, or foot-mounted. Motor nameplate rating shall be as indicated on the plans. Motor service factor shall be 1.15. Motors shall be suitable for operation with Power Supply. During continuous operation, motors shall be insensitive to line voltage variation of 10 percent above and below the rated motor voltage and to normal frequency variations described in NEMA MG-1. The motor shall be designed for stopping a free-wheeling impeller and accelerating that fan impeller from standstill to operating speed without exceeding the rated temperature rise.
 - 2. Motors shall be rated in accordance with NEMA MG-1 for the locked-rotor input (kilovolt amperes per horsepower) required to meet the specified acceleration performance. Motor and shaft shall be designed for full plug reversal. Motors shall have a minimum of Type H insulation and shall be rated for Class B temperature rise when tested at the service factor load as a minimum requirement.
 - 3. Nameplate horsepower shall be actual continuous brake horsepower developed without any consideration of the "air-over" factor.

4. The motors shall be designed for continuous operation for the time durations and temperatures specified in Article 1.09A, Design Temperature Conditions herein.
5. All fan motors shall be new. Components from motors subjected to high temperature testing shall not be used in the fabrication of the new motors supplied for this Contract.
6. Motors shall be equipped with factory-installed resistance space heaters within the motor enclosure to prevent condensation of moisture in the motor windings. Heaters shall be 120 volts, single phase. The heaters shall be provided with leads terminated in the Power Junction Box external to the fan housing.
7. Motor horsepower shall be as indicated on the nameplate. Horsepower input required by the fans shall not exceed the nameplate horsepower of the motors for pressure variations of plus or minus 1.50 inches water gauge along the design fan operating curve in either direction of airflow. Motors shall have a minimum overall efficiency of 90.0 percent at the rated load. The locked-rotor torque shall not be less than 145 percent of the motor full-load torque. Motor pull-up and breakdown torque percentages of full-load torque shall be in accordance with NEMA MG-1 for nameplate high speed horsepower. The locked-rotor current shall not exceed 6.5 times the full-load current with rated Power Supply at the motor terminals.
8. Each motor bearing shall be provided with a vibration detector for measuring bearing vibration. The detector sensor shall be permanently encapsulated, coated electronics using microprocessor digital circuitry, with transducer wired to the vibration monitoring device located in the Fan Instrument Panel external to the fan housing. The accuracy of the detector shall be a maximum of 20 percent of detector level within temperature range.
9. Vibration monitors shall provide high vibration alarm and trip contacts from each detector to the motor protection relay in the fan starter. The monitors shall incorporate a local digital display of vibration levels, and alarm and trip levels, and shall be equipped with alarm contacts to provide local audible and visual alarms of high vibration.
10. Motors shall be provided with six (two per phase) resistance temperature detectors (RTD's) wired to the Fan Instrument Panel. Analog signals from the RTD's shall be extended from the Fan Instrument Panel to the motor protection relay in the fan starter using shielded cables.
11. Each motor bearing shall be provided with one resistance temperature detector (RTD) wired to the Fan Instrument Panel. Analog signals from the RTD's shall be extended from the Fan Instrument Panel to the motor protection relay in the fan starter using shielded cables.
12. Minimum power factor of motors shall be 85 percent at the rated load.
13. The starting and accelerating torque on motor winding shall be sufficient to permit the motor rotor and fan impeller to attain full speed without tripping the

motor controller overload relays, which shall be set at a current corresponding to 140 percent of the motor full-load current.

B. Motor Materials and Components

1. Motor shafts shall be steel, designed and constructed to support and drive the fan impeller under all specified operating conditions.
2. Each motor shall have at least two ball or roller type grease-lubricated, electric motor grade, noise-tested bearings selected for the specified operating conditions of the fan motor unit. Determination of axial thrust load on motor bearings shall include addition of the weight of rotating assembly for vertically-installed fan-motor units. The bearings shall be based on AFBMA 9 or 11 and shall have a minimum L 10 life rating of 40,000 hours at maximum motor horsepower capacity and maximum speed based on the bearing load imposed by driven equipment.
3. Lifting lugs shall be provided on the exterior of motors.

C. Control wiring

1. All control wiring of motor and fan has to conform to the requirements of NFPA 130 and as described in Contract Specifications Section 26 05 24, Low Voltage Wires and Cables.

2.04 DEVICES

A. Proximity Probes:

1. A set of proximity probes shall be provided and installed on the motor / shaft of each fan in order to provide monitoring of direction and speed of rotation of the fan motor. Contractor shall coordinate with fan-motor manufacturer to confirm suitability of motor / shaft milling for the mounting and operation of the probes with the proximity probe manufacturer. Contractor shall ensure that the motor manufacturer provides probe enclosure design and mounting means to the motor shaft. Two transducer probes are required for each motor shaft and are to be installed in accordance with manufacturer's installation instructions and as shown on the associated Contract Drawings. Contractor shall also provide and install all associated controller, wiring, and accessories necessary for the operation of the proximity probes. The Controller shall be installed in the Fan Control Panel (FCP). The proximity probe controller shall provide speed and direction of rotation information including alarm and trip contacts back to the fan controller. The monitors shall incorporate a local digital display of speed and direction of rotation, and alarm and trip levels that shall be transmitted back to OCC.
2. Electrical current and voltage phase rotation detectors shall be provided for each motor of each fan in order to provide monitoring of direction and speed of rotation of the fan motor. Contractor shall coordinate with fan-motor manufacturer to confirm suitability of these detectors and for the mounting and operation of these detectors with the detector manufacturer. Contractor shall also provide and install all associated controller, wiring, and accessories necessary for the operation of

these current and voltage phase detectors. The Controller shall be installed in the Fan Control Panel (FCP). The current and voltage phase rotation detector controller(s) shall provide high current alarm and trip levels that shall be transmitted back to OCC.

3. Diaphragm type pressure sensors, two each shall be provided in a NEMA 4 enclosure. These sensors shall be connected to ¼ copper tubing probes mounted at each end of the fan. These copper tube probes shall be arranged to sense the positive and negative pressure produced on each side of the fan unit. The pressure sensors shall be connected to an associated controller, wiring, and required accessories. Contractor shall also coordinate the fan-motor manufacturer with the sensor manufacturer to provide the necessary mounting and operation of these sensors and controllers. The Controller shall be installed in the Fan Control Panel (FCP) and shall provide alarm and trip contacts from each sensor controller that shall be transmitted back to OCC.
4. All of the individual device controllers listed above shall be connected to OCC and shall provide both individual speed and rotation indications but also provide a trouble alarm if any of the controllers are in conflict with the other controllers.

2.05 SHOP FINISHES

- A. After fabrication and before assembly, all inside and outside surfaces of all fan housings, fan housing extensions, supports, fan-motor unit bases and exterior of fan motors shall be prepared in conformity to the requirements of SSPC SP-10 and shall be given a rust inhibiting coating, which may consist of an approved plastic coating, or bonderizing, or phosphatizing, followed by the application of a suitable rust inhibiting zinc-rich primer and finish epoxy and urethane paint that is resistant to abrasion and to exposure to elevated temperatures. Surface finish shall be capable of withstanding:
 1. Design Temperature Conditions specified in Article 1.09A herein without degradation of its protective quality, and without emitting toxic or noxious fumes.
 2. Two hundred hours in salt spray fog test, in accordance with ASTM B117. Immediately upon removal of the panel from the test, the film shall not show any visible blistering or rust spots, and there shall not be over 1/8 inch of rust creepage on either side of the scratch mark.
- B. Provide colors as directed by the District Representative.
- C. Applied and cured paint shall be tested to ensure that the specified dry film thicknesses are achieved. The dry film thickness of each coat shall be measured in place with a calibrated magnetic film thickness gauge. Measurement of dry film thickness shall be in accordance with the requirements of SSPC PA-2.
- D. Paint manufacturer's printed paint application instructions shall be submitted. Submit four samples of the specified primer paint and top coat paint coats applied together on light gauge carbon steel sheet. The paint coats shall be applied shingle fashion to expose each representative coat. The samples shall be 12 inches square and shall be marked with manufacturer's type and color designation.

- E. Machined surfaces not requiring painting shall be provided with a coating of anti-corrosion compound before leaving the place of manufacture.
- F. Surface finishes damaged during transport or assembly shall be restored to their original condition and color by the installing contractor.
- G. Application
 - 1. The minimum height of profile after completion of blast cleaning shall be 1.5 mils.
 - 2. Surfaces of motors to receive primer paint material shall be prepared in accordance with SSPC SP-3. Surfaces specified to receive paint shall receive one coat of primer paint material, two intermediate coats, and one top coat paint material.
 - 3. The top coats shall be tinted to differentiate between coats.
 - 4. The minimum dry film thickness of the primer coat shall be 3 mils Dry Film Thickness (DFT). Provide the manufacturer's recommended zinc-rich epoxy primer that is compatible with the substrate and finish materials indicated.
 - a. Ameron "Amercoat 68HS, 3 to 5 mils DFT; or
 - b. Carboline "858 Zinc-Rich Epoxy Primer", 3 to 5 mils DFT; or
 - c. Sherwin-Williams Zinc-Clad IV, or equal.
 - 5. The minimum dry film thickness of each intermediate and top coat shall be 3 mils DFT.
 - a. Two intermediate coats shall be high-build epoxy such as Ameron "Amerlock 400", Sherwin-Williams "Epoxy Mastic Aluminum II", Carboline "893 Epoxy", or equal.
 - b. Final top coat shall be urethane such as Ameron "Amerishield", Sherwin-Williams "Hi-Solids Polyurethane", Carboline "133 HB Aliphatic Polyurethane", or equal, capable of resistance to weather, abrasion, and salt solutions, having a wide selection of available colors.
 - 6. Primer paint material and top coat paint material shall be applied in accordance with the requirements of the paint material manufacturer's printed paint application instructions and in accordance with the applicable non-conflicting requirements of SSPC PA-1.

2.06 HARDWARE

- A. Fasteners
 - 1. In accessible areas, fasteners shall be hexagonal nuts, provided with heavy-duty lock washers.
 - 2. In inaccessible areas, fasteners shall be hexagonal head tap bolts, provided with heavy-duty lock washers.

3. Bolts shall not be less than one-half inch in diameter unless otherwise indicated.
4. Bolts and tap bolts shall be stainless steel and shall conform to the requirements of ASTM A 193, Grade B8M or B8MA, equivalent to AISI Type 316, with suitable lock washers.
5. Nuts shall be stainless steel and shall conform to the requirements of ASTM A 194, Grade 2H, equivalent to AISI Type 316.
6. Lock washers shall be stainless steel, equivalent to AISI Type 316, and shall conform to the requirements of ASME B18.21.1.

B. Anchor Bolts:

1. Anchor bolts shall be stainless steel and shall conform to the requirements of ASTM A 193, Grade B8M or Grade B8MA, equivalent to AISI Type 316, with suitable lock washers.
2. Anchor bolt nuts shall be stainless steel and shall conform to the requirements of ASTM A 194, Grade 2H, equivalent to AISI Type 316.

2.07 NAMEPLATES

- A. Each fan shall be provided with a stainless steel nameplate permanently stamped with the name and address of the manufacturer, Contractor's identification number, fan type, the Contract Drawing's designated fan number, shop order, serial number of fan, year of manufacture, maximum safe operating speed of fan in revolutions per minute, fan impeller diameter, maximum design operating speed and corresponding volume of air delivered and the fan total pressures at density specified. The nameplate shall be securely screwed or riveted to the exterior of fan housing in a conspicuous position.
- B. Each fan shall be provided with a stainless steel enamel plate which shall bear, in numerals not less than 3 inches high, the District's fan designation numbers. The plate shall be securely screwed or riveted to the exterior of the fan housing adjacent to the fan nameplate.
- C. Each motor shall be provided with two identical stainless steel nameplates permanently stamped with the name and address of the motor manufacturer, the motor horsepower, NEMA motor frame number, voltage, phase, frequency, insulation type, full-load current, locked rotor indicating code letter, minimum overall efficiency, the design temperature rise over ambient of the motor, maximum ambient temperature, type of duty, the terminal connection chart for the motor, rating of space heater, speed in revolutions per minute, service factor, motor type and serial number, maximum starts per day, ABMA bearing code and shop order number. One nameplate shall be furnished on the motor and the other either riveted or screwed on the exterior of the fan housing immediately adjacent to the fan nameplate.
- D. Each fan shall be provided with a 10-inch-long by 1 1/2-inch-wide metallic arrow that shall indicate the direction of forward and reverse airflow. The arrows shall be rigidly and permanently attached to the fan housing, in a position that can be readily

viewed when the fan is in its final operating position. Three-quarter-inch letters shall be engraved on the arrow to read as follows: "EXHAUST (FORWARD AIRFLOW)" and "SUPPLY (REVERSE AIRFLOW)."

- E. Each fan shall be provided with a 10-inch-long by one-inch-wide stainless steel plate permanently stamped with the labels "Grease Line Supply Port" and "Grease Line Exit Port".
- F. All the nameplates shall be Type 316 stainless steel of not less than 10-gauge-thick and shall be placed to be readily conspicuous after installation.

2.08 FACTORY TESTS AND INSPECTIONS

A. General

1. Contractor shall perform factory tests and inspections as described below. The District may, at their option, witness any or all tests. Observations made during the tests and all test results shall be recorded in a document form, certified by Contractor and submitted to the District Representative for approval. No less than three weeks written notice shall be furnished to the District Representative before the factory tests. No test notification shall be sent until all of the factory test procedures have been submitted, reviewed and approved.
2. Tests described herein shall not preclude additional standard tests normally performed by the manufacturers for similar equipment.
3. Pre-production fan-motor units used for testing may be furnished as production units after pre-production testing if the units satisfactorily pass all specified factory tests as described below under production fan tests, except for fan-motor units subjected to the elevated temperature test. Motors, motor shafts, and fan rotating assembly components used in the elevated temperature test shall not be furnished in production fan motor units.
4. All of the pre-production tests shall be performed for each fan-motor unit model supplied. All of the pre-production test results shall be submitted and accepted by the District prior to the start of construction of the production fan-motor units. The Pre-production tests include the overspeed test, vibration test, elevated temperature test, air performance test, non-destructive inspections (NDI), strain test, sound test, reversal test and running (200 hr) test. Production tests include overspeed test, vibration tests, run-in (24 hr) test, NDI test.
5. All fan performance tests, production and pre-production shall utilize a motor control center (MCC) and power supply source similar to the power supply and motor controller being provided, under the Contract, at the actual field installation. Increasing the transformer tap, doubling up on transformers or similar modifications to the fan motor power supply shall not be acceptable.
6. The test procedures shall be performed for each fan-motor unit model supplied.
7. The tests shall be sequential in the order prescribed below. Any fan-motor unit or component that fails to satisfactorily perform any test as specified shall be

considered unacceptable. Failing parts shall be replaced and the entire unit shall be re-tested.

8. Before actual testing is begun on any fan-motor unit to be furnished, Contractor shall submit full details of all test procedures including the sequence in which they are to be run and the expected duration of the test, samples of all test report forms, and full details of the methods by which the raw test data is to be reduced for submittal to the District Representative for approval.
9. Test details shall also include a list of test instrumentation, containing name of manufacturer, model type, serial number, and calibration date. Documentation shall be furnished to verify that test instrumentation has been calibrated not more than nine months before the tests.
10. Except as required for the independent motor factory test, all tests shall be performed by Contractor at the fan manufacturer's plant or other District Representative approved location.
11. All expenses in connection with or incidental to the factory testing shall be borne by Contractor.

B. Motor Tests

1. Motors shall be tested in accordance with the procedures specified in IEEE Publication 112 and NEMA MG-1. Using full voltage option, motor tests shall be performed for one pre-production motor of each size by an independent testing company approved by the District. Tests performed for the pre-production motor by the motor manufacturer will not be acceptable. This shall not preclude preparatory testing at the manufacturer's facility prior to conducting the independent motor factory test. A certified test report and certified performance curves verifying the theoretical motor performance curves for all of the coordinates specified shall be submitted to the District Representative for approval. Performance curves for each type and size of fan motor shall be plotted to a scale that will facilitate accurate readings. The District Representatives may, at their option, witness the independent motor factory tests.
2. One motor of each nameplate horsepower rating and service factor shall be tested for forward and reverse modes as follows:
 - a. Full voltage tests to obtain actual fan motor performance curves from standstill to full speed verifying the theoretical fan motor performance curves at 110 percent, 100 percent, 90 percent and 85 percent rated voltage previously submitted and other data specified hereinafter.
 - 1) Full-load current in amperes
 - 2) No-load current in amperes
 - 3) Full-load input in kilowatts
 - 4) No-load input in kilowatts
 - 5) Locked-rotor current in amperes

- 6) Locked-rotor input in kilovolt amperes
- 7) Locked-rotor, pull-up and breakdown torque in foot-pounds
- b. Tests to determine:
 - 1) Winding resistance
 - 2) Losses, no-load and full-load
 - 3) Temperature rise - motor thermal curves
 - 4) Dielectric tests
 - 5) Visual bearing inspection
3. Heat Run Test
 - a. Each pre-production motor shall be connected to a dynamometer, loaded to design duty and operated continuously until winding and bearing temperatures stabilize.
 - b. Temperatures shall be considered stabilized when no more than a one-degree Celsius increase in temperature is observed over a one-half hour period. Winding and bearing temperatures shall be recorded on one-half hour intervals throughout the test.
 - c. Production motors and spare motors for each size specified shall not be released for manufacture until the pre-production motor has satisfactorily completed the independent motor factory test, the heat run test and the high temperature test.
4. The remaining motors shall be tested at their rated synchronous speed in both the forward and reverse direction. Tests shall include the following:
 - a. Winding resistance
 - b. No-load current in amperes
 - c. Dielectric tests
 - d. No-load speed
 - e. Visual bearing inspection
 - f. Locked-rotor current in amperes
5. The following data shall be plotted for each speed and direction as ordinates versus horsepower as abscissas from no load up to not less than 115 percent full load:
 - a. Current, in amperes
 - b. Efficiency, in-percentage
 - c. Power factor, in-percentage
6. The following data shall be plotted for each motor horsepower size as ordinates versus revolutions per minute as abscissas:

- a. Current in amperes
 - b. Torque in foot-pounds
 - c. Power factor in percentage
7. Test data for the certified performance curves shall be recorded at the rated voltage and frequency of the motor, continuously over the speed range from standstill to rated rotational speed of the motor.

C. Elevated Temperature Test

1. One pre-production fan-motor unit of each size provided shall be installed in an elevated temperature duct loop and subjected to Design Temperature Conditions Article 1.09A herein.
2. The fan-motor unit shall be operated at design airflow and pressure during the test.
3. Air temperature in the heat loop shall be recorded continuously throughout the test.
4. Motor winding and bearing temperatures, voltage and current shall be measured and recorded at a minimum of five-minute time intervals throughout the test.
5. Each fan-motor unit shall still be operating at the design duty at the end of the elevated temperature test with no rubbing of the fan blade tips against the interior of the fan casing. In the event that expansion of the fan blades due to increased temperature results in any blades contacting the casing, the Contractor shall ensure that the manufacturer submits a remediation plan to the District Representative for approval.

D. Non-Destructive Inspection

1. Radiographic Inspection

- a. Provide a certification that, for all fan hubs and blades, x-rays have been taken in accordance with ASNT standards, with notation of the x-ray numbers, and also that fluorescent dye penetrant examination has been performed. In addition, provide a complete list of the identification numbers for all hubs and blades actually installed in each fan.
- b. Certification of visual acceptability, the x-ray procedure, the x-ray films, and proof of traceability of conformance with alloy specifications of the metal used to cast the hub and blades shall be submitted to the District Representative for approval. The identification number of the x-ray film shall be etched on each blade and hub at a location that will not create adverse stress concentrations to reduce the design safety factor at the point of critical stress.
- c. The x-ray films shall be kept on file by the manufacturer for a minimum of five years.

2. Ultrasonic Examination

- a. Provide certification that, for all forged fan hubs and blades, ultrasonic examination has been performed in accordance with ASTM A 388. In addition, provide a complete list of the identification numbers for all hubs and blades actually installed in each fan.
- b. Certification of visual acceptability, the ultrasonic examination procedure, and proof of traceability of conformance with alloy specifications of the metal used to forge the hub and blades shall be submitted to the District Representative for approval.
- c. The ultrasonic examination results shall be kept on file by the manufacturer for a minimum of five years.

3. Magnetic Particle Examination

- a. Provide certification that, for all forged fan hubs and blades, mag. particle examination has been performed in accordance with ASTM E 709. In addition, provide a complete list of the identification numbers for all hubs and blades actually installed in each fan.
- b. Certification of visual acceptability, the mag particle examination procedure, and proof of traceability of conformance with alloy specifications of the metal used to forge the hub and blades shall be submitted to the District Representative for approval.

E. Overspeed Tests

- 1. All fan rotor assemblies shall be subjected to an overspeed test before assembly of the complete fan motor units.
- 2. After non-destructive inspection and after static and dynamic balancing, each completely assembled fan impeller shall be overspeed tested in both directions. Spin testing of individual components, such as blades and rotors, in lieu of testing complete impellers, is not acceptable. Each fan impeller shall be spun from standstill up to 125 percent of the maximum design operating speed for a period of not less than three minutes. Following each spin test, a visual inspection for surface defects shall be made by Contractor. Certificates of visual acceptability shall be submitted to the District Representative for approval.

F. Vibration Tests

- 1. After assembly, each fan-motor unit shall be checked for bearing operation in both directions of rotation. Defective bearings shall be replaced, and the fan shall be re-checked before further testing. The vibration shall be measured in two radial planes, 90 degrees apart, and in the axial direction. Measurements shall be made for each radial plane at the front and rear of the fan. Measured maximum vibration shall not exceed peak-to-peak amplitudes of 0.35 mils (0.00017 inch) for fans operating at a nominal speed of 1,200 rpm or less.
- 2. If measured vibration amplitude exceeds the specified maximum, or if the specified vibration measurements reveal unacceptable vibration at any frequency other than rated design operating speed, vibration amplitude shall be measured

and recorded continuously as the fan is accelerated from a standstill to rated design operating speed, and as the unit coasts down from rated design operating speed to a standstill. The amplitude versus frequency chart shall be analyzed by Contractor (Fan Manufacturer) to determine the cause(s) of the unacceptable excessive vibration. Resonant frequencies shall be determined and shall be demonstrated as not to occur within fan operating ranges. The analysis shall be submitted to the District Representative for approval and the cause(s) shall be corrected. The District Representative shall be furnished final vibration amplitude readings on all fan bearings.

G. Fan-Motor Unit Performance Test

1. One pre-production fan-motor unit which has satisfactorily passed the preceding test and inspections specified, shall be tested in accordance with the procedures specified in the AMCA 210, latest edition, using a test set-up approved by the District Representative.
2. Fans shall be tested without flow cones or any other static regain devices. The fans shall be tested at the blade angle that shall produce the required volume of air at the required system pressure, and the minimum and maximum blade angle. Test data shall be recorded on AMCA data submittal forms, or the equivalent thereof, as approved by the District Representative. Certified test data, and certified performance curves for all of the coordinates specified shall be submitted to the District Representative for approval.
3. Performance tests shall cover the range of airflow rates from no flow to free air delivery. Performance tests of ventilation fans shall cover this range of airflow rates in both directions of airflow. Actual fan performance shall not be less than Contract values.
4. Performance tests shall include starting fan from a standstill against a system resistance that will result in the fan operating at the airflow and pressure indicated on the fan schedule. Starting tests shall be performed for both forward and reverse airflow directions at rated voltage, 90 percent of rated voltage and 85% of rated voltage. A Power Quality Analyzer shall be used to measure and record current, voltage, power factor and power versus time during starting from standstill to a period of 5 minutes after fan reaches rated speed, with meter set to measure and record data on one-second intervals.
5. The fan shall be calibrated for airflow capacity versus annulus velocity, using laboratory grade pitot tube in the annulus and mounted through the bushing in the fan housing during performance test.
6. Triaxial Strain gauges shall be applied to two blades per impeller and to the hub of the unloaded impeller of each fan. To accurately measure strains and stresses developed in each rotor, one strain gauge at the midpoint and one strain gauge at the tip of blades on each side shall be applied on minimum of two blades. In addition, one strain gauge shall be applied on impeller hub for each strain-gauged blade. The strains developed during performance testing shall be continuously measured and monitored. The measured strains produced under the performance test load shall be used to calculate the corresponding stresses.

Stresses found shall not exceed 60 percent of the material yield strength at 482 degrees Fahrenheit. The methods of strain measurement and stress calculation shall be submitted to the District Representative for approval. Contractor shall submit the manufacturer's certification that the measured strains and the corresponding calculated stresses represent the strains and stresses developed in all other blades of the pre-production fan motor unit being tested. Calculated maximum expected stresses, and the design properties of the material used to fabricate the impeller blades and hub, shall also be submitted to the District Representative for approval. Strain gauge testing shall be performed using the same testing set-up and operating conditions as the fan full-scale performance test, and shall be performed at the design duty blade angle setting with the fan operating at the design duty airflow and pressure.

7. In the event that the tests show that the fan-motor units do not comply with the requirements as to characteristics and performance, or that the brake horsepower will exceed by five percent or more the brake horsepower shown in the theoretical data submitted by Contractor, the fan motor units will be rejected until the specific requirements are met.
8. Upon the completion of the fan-motor units performance tests, submit two complete copies of all raw test data.
9. After the completion of fan-motor units performance tests, submit for each fan-motor unit model supplied, performance curves and tables of performance data calculated from shop test data for each blade angle tested, at each of the test points at each rotational direction and speed.
10. The tables shall consist of numerical values at each of the test points for the following:
 - a. Volume of air delivery in cubic feet per minute
 - b. Fan static pressure in inches of water
 - c. Fan total pressure in inches of water
 - d. Fan outlet velocity pressure in inches of water
 - e. Fan total efficiency in percent
 - f. Horsepower input to fan impeller
 - g. Fan speed in revolutions per minute
 - h. Current input in amperes versus time for fan starts at rated voltage, 90 percent of rated voltage and 85 percent of rated voltage
 - i. Voltage in volts versus time for fan starts at rated voltage, 90 percent of rated voltage and 85 percent of rated voltage
 - j. Power factor for fan starts at rated voltage, 90 percent of rated voltage and 85 percent of rated voltage
 - k. Motor power input in kilowatts and power factor rated voltage, 90 percent of rated voltage and 85 percent of rated voltage

I. Number of phases and frequency

11. Submit fan-motor unit performance curves verifying the theoretical performance curves previously submitted. Test points shall be indicated on performance curves.
12. Submit all electrical curves for fan starting testing.

H. Sound Test

1. Pre-production unit which has satisfactorily passed all preceding tests and inspections specified shall be tested at the design duty on the performance test set up in accordance with the test procedure of ANSI S12.36 to obtain sound power level data at eight octave band center frequencies from 63 Hertz to 8,000 Hertz.
2. Fan shall be tested at the design duty blade angle setting with the fan operating at the design duty airflow and pressure in both forward and reverse directions. Test data shall be submitted to the District Representative for approval in tabular form.

I. Reversal Test

1. One pre-production fan-motor unit for each size supplied which has satisfactorily passed all preceding tests and inspections specified shall be subject to reversal tests. These tests shall require operation at rated operating speed at the approximate design duty airflow and pressure for approximately three and a half hours, and shall require three cycles of rotation reversal. A cycle of rotation reversal is defined as reversal from one direction of motor impeller rotation to the other direction of rotation, and then back to the first direction of rotation.
2. The reversal test shall begin with the fan-motor unit operated for a period of 30 minutes in the forward direction of airflow.
3. At the end of the first 30-minute period of operation in the forward direction of airflow, the motor shall be electrically reversed, with a 10-second time delay imposed between the interruption of power and re-energizing of the motor for reversed rotation. The fan shall achieve full speed rotation in a maximum of 15 seconds after re-energizing the motor for reverse rotation.
4. After the motor has been re-energized, the fan shall be operated for a period of 30 minutes in the reverse direction of airflow.
5. The test shall be continued, with alternating 30-minute periods of operation in the forward and reverse directions of airflow, until six rotation reversals have been performed. At the end of each 30-minute period of operation, the fan-unit motor shall be electrically reversed, with a 10-second time delay imposed between each change in direction until six rotation reversals have been performed. The fan shall achieve full speed rotation in a maximum of 15 seconds after re-energizing the motor for reverse rotation.

6. After three cycles of rotation reversal, i.e., six reversals of the direction of motor and impeller rotation have been performed, the fan-motor unit shall be operated for a period of 30 minutes.
 7. At the end of the last 30-minute period of operation, the fan shall be de-energized, and permitted to coast to a standstill.
 8. Resistance of the cold motor winding insulation shall be measured just before the start of the reversal test, and the motor winding insulation shall be measured immediately after the end of the test. In addition, the temperature of the motor windings and of the motor frame shall be continuously recorded throughout the test and the acceleration time, speed, voltage, frequency, amperes, and kilowatts shall be recorded during each reversal. Certification of successful performance of the reversal test and certified test data shall be submitted to the District Representative for approval.
- J. Pre-production Running Test: One pre-production fan-motor unit for each size supplied which has satisfactorily passed all preceding tests and inspections specified shall be operated continuously for 100 hours in the forward direction of airflow, de-energized and allowed to coast to a stand-still, then re-energized and operated continuously 100 hours in the reverse direction of airflow. The fan-motor unit shall be checked for rough operation, as a minimum, every 10 hours and a record made of each check. This record shall be included in the completed fan test records.
- K. Run-In Test: Each ventilation fan shall be operated continuously for a total of 24 hours, 12 hours in the forward (exhaust) mode and 12 hours in the reverse (supply) mode of rotation. During reversal, fan shall be allowed to coast for a period of five minutes before being restarted in the reverse direction. Fans which have passed the Pre-production Running Test will be deemed to have passed this test. The following data shall be measured and recorded after each fan reaches rated speed and at one-hour intervals thereafter:
1. Time
 2. Ambient temperature in degrees Fahrenheit
 3. Absolute barometric pressure in inches of Mercury
 4. Motor winding temperatures in degrees Celsius
 5. Motor bearing temperatures in degrees Celsius
 6. Motor bearing vibration levels in inches per second
 7. RPM (revolutions per minute)

PART 3 – EXECUTION

3.01 INSTALLERS

- A. The District Representative shall be advised in writing of the name and title of the proposed manufacturer's field service engineer, who upon District Representative approval shall have complete authority to represent and to act for Contractor.
- B. Contractor shall ensure that the manufacturer's field service engineer assists the Contractor with the installation of the fan-motor units.
- C. Equipment shall be installed in accordance with the approved Shop Drawings and the respective equipment manufacturers' installation instructions and recommendations.

3.02 EXAMINATION

- A. Prior to installation, the Contractor shall measure or survey the facilities and prepare a layout and section drawing showing the centerline of installation and top of foundation elevations. The horizontal centerline shall be based on the centerline of the tunnel-side opening frame. Vertical control shall be based on the tunnel-side opening frame such that all pieces line up with the tunnel-side opening. Submittal and approval of this layout and section drawing is required before installation can proceed.
- B. Contractor shall note any items that may infringe on the necessary clearances for the equipment.

3.03 PREPARATION

- A. Ventilation equipment shall be carefully protected at the Jobsite in a manner to preclude the possibility of damage to the equipment.
- B. The permanent anti-condensation motor space heaters for the fan motors and the damper motors shall be energized with temporary power before and after installation until permanent power is available. Contractor shall energize the motor space heaters within 24 hours after the fan is delivered to the Jobsite.
- C. Construct all concrete pads, supports, and foundations necessary to support the equipment. Provide all anchor bolts, rebar ties, and sleeves. Anchor bolt sleeves shall allow for minimum 1/4-inch movement of the anchor bolts. Anchor bolt sleeves under rubber pads shall allow for the thickness of any vibration isolation sleeves. These foundations shall allow for a nominal 3/4-inch thick grout to be placed under the equipment support.

3.04 ERECTION

- A. The manufacturer's rigging instructions shall be carefully followed.

- B. Set equipment in place to the indicated lines and levels. Shim to required levels with stainless steel shims. All flange faces shall be aligned and parallel prior to bolt-up. Flexible joints shall only be installed after all hard flange joints are connected and shall be used only to close aligned parallel connections between hard flanges. Flexible joints shall not be used to correct misalignment conditions.
- C. Where rubber pads are specified under rotating equipment for vibration isolation, provide a minimum 1/2-inch thick continuous steel plate underneath the pad to allow the equipment to be set on shims prior to grouting. Holes for anchor bolts shall allow for any vibration isolation sleeves or washers.
- D. When installed, the orientation of each fan, as to motor end, shall be as indicated on the Contract Drawings.

3.05 INSTALLATION

- A. Fans shall be connected to transition companion flanges with 1/4-inch-thick solid gasket between; width of gaskets shall be same as flange width.
- B. Apply anti-seizing compound to the threads of stainless steel bolts and studs.
- C. After all bolt-ups are completed and accepted, grout all foundations and anchor bolt sleeves.
- D. After installation and before the start of testing, the equipment shall be lubricated. Equipment shall be checked for clearances and proper alignment.
- E. Perform all non-power alignment, adjusting, and testing as required by the respective manufacturer's installation procedures.

3.06 ELECTRICAL AND CONTROLS

- A. All interconnecting power and wiring between ventilation components shall be installed, terminated, and tested by the Contractor. Contractor shall provide access to equipment and resolve discrepancies in ventilation equipment as required.
- B. Inspect all power and control wire connections and perform all continuity testing to ensure proper installation, and meger testing to ensure insulation integrity is maintained after installation is completed. Perform all functional alignment, adjusting, and testing as required by the equipment manufacturer's instructions.
- C. When the electrical installation work is completed and verified, advise the District Representative so that field tests can be performed. After field testing is completed, restore all equipment to its proper operating condition.
- D. All power and control wiring external to the ventilation equipment shall be provided by the Contractor.

3.08 FIELD QUALITY CONTROL

- A. All installation procedures shall conform to the equipment manufacturer's instructions. Checklists shall be used and signed off by the responsible installer as well as by the respective equipment manufacturer's representative.
- B. Contractor shall provide the manufacturer's field service engineering and inspection reports to District Representative to ensure that the fans are properly installed and tested.
- C. Field service shall be performed periodically as required during the construction and testing of the District's Contract. Field service shall not be less than 14 Days.
- D. The duties, responsibilities, and qualifications of the field service engineer shall be:
- E. Responsible for advising the installation Subcontractors on the proper procedures for the installation of the fan equipment.
- F. To have a thorough knowledge of the ventilation fans and the associated systems.
- G. To have a thorough knowledge of the test results and performance requirements of all material and equipment supplied.
- H. To prepare and submit to the District a typewritten report on the activities and findings for each visit made within 15 Working Days of the visit

3.09 FIELD TEST

- A. Upon completion of the installation of all ventilation equipment at the fan room and the installation and verification of the power and local control wiring, Contractor shall notify the District Representative in writing at least four weeks before the field testing to have the District Representative present to witness the tests. Contractor shall also notify the field service engineer for assistance in the performance of the tests. Contractor shall submit field test procedures for testing of the fan motor units in the field.
- B. Contractor shall ensure that field tests are performed under the technical guidance and supervision of the manufacturer's field service engineer. The field service engineer shall provide the field test instrumentation and perform the tests. The field service engineer shall measure and record the vibration amplitude; power consumption; no-load, starting and full-load voltages; starting and full-load currents; and acceleration time.
- C. Time of field run-in testing shall be one hour per fan in each direction. Vibration and electrical measurements shall be recorded for each fan motor unit at design speeds in each direction. Where multiple fans are installed in the same room, all fans shall be operating simultaneously when recording vibration and electrical data.
- D. Field testing for the ventilation equipment shall not commence until permanent electric service and local controls can be provided for testing.

- E. Visual and operating tests required are as follows:
1. Each fan-motor unit shall be checked for obviously rough operation after the fans are installed. Defective bearings shall be replaced with new bearings and the fan(s) shall be re-checked. Amplitude and frequency of radial and axial vibrations at the bearings shall be measured, recorded, and checked for conformity to these Specifications.
 2. Each fan-motor unit on which the specified vibration field tests have been successfully performed shall be tested to confirm that such fans are fully operational.
 3. Each ventilation fan-motor unit shall be proven operational in both directions of airflow. One full reversal test shall be performed on each installed fan. The field reversal test shall include one 30 minutes of forward operation, followed by de-energizing for 10 seconds, followed by re-energizing in the reverse direction of rotation for 30 minutes. The fan shall achieve full speed rotation in a maximum of 15 seconds after re-energizing the motor for reverse rotation. These tests shall be measured, recorded, and checked for conformity to these Specifications.
 4. Verify proper operation of the proximity probes and all fan operation instrumentation equipment indicating the direction and speed of rotation of the fans. This would include proximity, phase rotation, current and pressure sensing equipment. These tests shall be measured, recorded, and checked for conformity to these Specifications.
 5. Field measurements required are as follows:
- F. Tunnel Airflow Performance Test: The last portion of the field tests shall be the measurement of air movement within the tunnel produced by the ventilation system.
1. The District Representative shall provide Contractor with details on locations for the measurements, the testing conditions (such as ventilation system operating requirements and the location of stopped trains), and the test results required for each location at least 180 Days before the scheduled date of test initiation. Air velocity measurements of the entire tunnel cross section shall be performed in order to measure the average airflow (in standard cubic feet per minute) through the cross section as determined by the log-Tchebycheff (log-T) rule. For each measurement location, a minimum of two air velocity measurements of the entire cross section shall be taken and averaged, and the averaged measurements shall not vary by more than two percent. If two sets of measurements vary by more than two percent, additional measurements shall be taken until two consecutive sets of measurements do not vary by more than two percent. The measurements shall account for the effects of the tunnel portals, changes in horizontal curvature, and location and distance from the stopped train. Contractor shall make the necessary arrangements with the District Representative to schedule the tests and to use stopped trains during the actual testing period. Train locations shall be as determined by the District Representative before testing.

2. Contractor shall submit to the District Representative, for approval by the District Representative, a written test program at least 45 Days before the scheduled date of test initiation and meeting the requirements of Contract Specifications Section 23 05 93, Testing, Adjusting, and Balancing for HVAC. This test program shall contain, as a minimum, the resumes of the Key Personnel participating in the test phase, the specific make and model numbers of the test equipment to be used, and a specific and detailed procedure to be followed for the set up of equipment and for the sampling, recording, and reduction of the test data.
 3. Contractor shall provide the District Representative with the measured test results. If the District Representative determines that the measured air velocities are less than the required "cold" air velocities, Contractor shall be notified in writing to increase the fan blade angles in order to produce the required tunnel airflow velocities. The field measurements shall then be repeated in order to verify that the required tunnel airflows have been achieved. If the increased fan airflows cause overloading of the fan motors, Contractor shall advise in writing on the extent of the overload.
 4. The District Representative shall be notified in writing at least two weeks before the initiation of this testing phase in order to coordinate the use of train(s) and to program the appropriate ventilation system operation.
 5. Sound Test: Sound pressure levels, measured in dB(A) shall be measured and recorded at platform level near each fan room with all Station fans operating. Background sound pressure levels shall be recorded before and after any fan noise measurement. Sound pressure levels shall be recorded in each octave band.
 6. These tests shall be performed by qualified personnel (employees of Contractor or a Subcontractor) who have been approved by the District Representative. The overall responsibility for this measurement program shall belong to Contractor.
 7. Air velocity measurements shall be made in each tunnel ventilation zone (between vent structures and between vent structures and stations or portals) of the entire tunnel. Cross sections shall be performed in order to measure the average airflow (in standard cubic feet per minute) through the cross section as determined by the log-Tchebycheff (log-T) rule. For each measurement location, a minimum of two air velocity measurements of the entire cross section shall be taken and averaged, and the averaged measurements shall not vary by more than two percent. If two sets of measurements vary by more than two percent, additional measurements shall be taken until two consecutive sets of measurements do not vary by more than two percent.
- G. After completion of all field tests and after the final visit by the field service engineer, Contractor shall submit a field test and inspection report. Field test report shall include copies of raw data, measured results, calculations, and all data derived from tests to confirm compliance with specified performance, noise, vibration and equipment efficiencies.

3.10 PROTECTION

- A. Fans shall be allowed to free wheel until beneficial use is accepted. Contractor shall protect openings to prevent unauthorized access.

END OF SECTION 23 34 14